

Improved Method for Generating Influenza Viruses and Vaccines

Government Interest

This invention was made in part with U.S. Government support under National Institutes
5 of Health grant NIAID N01 AI95357. The U.S. Government may have certain rights in
this invention.

Field of the Invention

This invention relates to the generation of influenza viruses and vaccines. The invention
10 also relates to methods for making and using high-titer reassortant viruses for generating
vaccine compositions.

Background

The influenza virus is responsible for a respiratory disease that may affect up to
20% of the population annually and, on average, kills approximately 20,000 people each
15 year in the United States alone. Symptoms of the virus include sudden fever, chills,
headache, myalgia, sore throat and a non-productive cough. Serious respiratory
complications, including pneumonia, can develop. Recently, outbreaks of influenza A
H5N1 have presented serious disease in humans and birds. Aquatic birds are the natural
host for the influenza virus, making it impossible to eradicate the virus. Thus, the need
20 for continued development of influenza treatments and vaccines.

The virus' success in causing disease is due to its ability to evade the immune
system by undergoing antigenic change, which is believed to occur when a host is
infected simultaneously with both an animal influenza virus and a human influenza virus.
Influenza viruses have a segmented genome which contains eight negative-sense RNA
25 (nsRNA) gene segments (PB2, PB1, PA, NP, M, NS, HA and NA) that encode at least 10
polypeptides, including RNA-directed RNA polymerase proteins (PB2, PB1 and PA),
nucleoprotein (NP), neuraminidase (NA), hemagglutinin (subunits HA1 and HA2), the
matrix proteins (M1 and M2) and the non-structural proteins (NS1 and NS2) (Krug et al.,
In The Influenza Viruses, R.M. Krug, ed., Plenum Press, New York, 1989, pp. 89-152).
30 During reassortment in the host, the human virus may incorporate the animal HA or NA
surface protein genes into its genome; thus, producing a new influenza subtype.

In addition to antigenic shift, viruses undergo antigenic drift, via point mutations in the HA and NA surface proteins. This also allows the virus to evade the immune system.

Current methods for preparing vaccines

5 Until recently, the only influenza vaccines available in the United States were inactivated influenza vaccines. In June 2003, the FDA approved the use of a live attenuated influenza virus vaccine in healthy children and adolescents, 5-17 years of age, and healthy adults, 18-49 years of age. The current vaccines contain two components of influenza A, H1N1 and H3N2, and an influenza B component. Over the last several
10 years, at least one of the components had to be changed each year due to antigenic drift. Clinical isolates of human influenza virus are taken from infected patients and are reassorted in embryonated chicken eggs with a laboratory-adapted master strain of high-growth donor virus, the A/PuertoRico/8/34 (PR8) influenza strain. The purpose of this reassortment is to increase the yield of candidate vaccine strains achieved by recombining
15 at least the HA or NA genes from the primary clinical isolates, with the six internal genes of the master strain donor virus. This provides high growth reassortants having antigenic determinants similar to those of the clinical isolates (Wood, J.M. and Williams, M.S., Textbook of Influenza. Blackwell Science LTd, Oxford, 1998; Robertson et al, Biologicals, 20:213, 1992). Vaccines are prepared by growing this reassorted viral strain
20 in embryonated eggs and then inactivating the purified virus by chemical means.

 In the case of a pandemic, chicken eggs will likely be insufficient and suboptimal for influenza vaccine production. Disadvantages of using enbryonated chicken eggs are (1) the lack of reliable year-round supplies of high-quality eggs and the low susceptibility of summer eggs to influenza virus infection (Monto, AS et al., J. Clin Microbiol, 13:233-
25 235, 1981, (2) cultivation of influenza A and B viruses in eggs can lead to the selection of variants characterized by antigenic and structural changes in the HA molecule (Katz, JM, et al., Virology 156:386-395, 1987; Robertson, JS., et al., Virology 143:166-174, 1985; Schild, GC., et al., Nature (London) 303:706-709, 1983), (3) the inability of some viruses to grow in embryonated eggs (Monto AS, et al., J. Clin. Microbiol. 13(1): 233-235, 1981)
30 and (4) the presence of adventitious agents in eggs can jeopardize the preparation of live, attenuated influenza virus vaccines. The use of chicken eggs for inter-pandemic influenza

vaccine production requires detailed planning up to six months prior to manufacture to ensure an adequate supply of embryonated eggs (Gerdil, C, Vaccine 21(16): 1776-1779, 2003).

New methods – reverse genetics

5 Recently developed reverse-genetics systems, based entirely on cDNA, have allowed the manipulation of the influenza viral genome (Palese et., Proc. Natl. Acad. Sci. USA 93:11354, 1996; Neumann and Kawaoka, Adv. Virus Res. 53:265, 1999; Neumann et al., Proc. Natl. Acad. Sci. USA 96:9345, 1999; Fodor et al., J. Virol. 73: 9679, 1999). Furthermore, an eight plasmid system that expresses the nsRNAs from a pol I promoter
10 and the coexpression of the polymerase complex proteins result in the formation of infectious influenza A virus (Hoffmann et al., Proc. Natl. Acad. Sci. USA 97:6108-6113, 2000). This technology allows the rapid production of "custom made" vaccines from cDNA for use in pandemic emergencies. It provides the capability to attenuate pathogenic strains (Subbarao, et al., Virology 305; 192-200, 2003) and eliminates the
15 need to screen reassortant viruses for the 6+2 configuration. The major disadvantage associated with this methodology is the need to use vaccine approved cell lines.

Cell Lines

 The commonly used cell lines for rescue of influenza viruses from cDNA are 293T and Madin-Darby canine kidney (MDCK) cells. The 293T cell line is a transformed
20 cell line and is therefore unlikely to be used for human vaccine production, and there are concerns over the tumorigenic potential of MDCK cells (Govorkova EA, et al. J. Virol 70(8): 5519-5524, 2001). Additionally, the utilization of the host specific RNA polymerase I promoters in the reverse genetics systems limits the cell lines to those of human or primate origin.

25 African green monkey kidney (Vero) cells are characterized, approved and certified by the World Health Organization (WHO) for production of human vaccines. However, Vero cells, while certified, were previously found unsuitable for large-scale production of human influenza virus vaccines. For example, the growth of influenza B in Vero cells was greatly restricted as compared to MDCK cells (Nakamura et al., J. Gen.
30 Virol. 56:199-202,1981). Additionally, attempts to use Vero cells to evaluate the rimantadine sensitivity of human H1N1 and H3N2 influenza A viruses gave ambiguous

results, due to the low titers of viruses produced in these cells, as compared with MDCK cells (Valette et al., *Antimicrobiol. Agent and Chemotherapy* 37:2239-2240, 1993). Thus, these and other studies indicate that influenza viruses have not previously replicated well in Vero cells, making them unsuitable for large-scale vaccine production. (Demidova et al., *Vopr. Virosol (Russian)* 346-352, 1979); Lau & Scholtissek, *Virology* 212:225-231, 1995).

The most widely used master strain, A/PuertoRico/8/34, produces a high titer virus in MDCK cells after rescue in MDCK and 293T mixed culture, which is suitable for research purposes. However, it does not produce a high titer virus in Vero cells, mammalian cells approved for use in generating vaccine for humans. By passaging an H1N1 reassortant isolate, A/England/1/53, multiple times in Vero cells, Govorkova EA, et al., *J. Infect. Dis.* 172(1):250-253, 1995, derived a high-yielding influenza virus. This reassortant virus was reported to contain the surface glycoprotein genes from A/England/1/53 and the remaining genes from A/Puerto Rico/8/34 (H1N1), the commonly used vaccine master strain.

There is a great urgency to develop improved cell culture systems suitable for influenza vaccine production for use in humans, which is a priority for the World Health Organization (Stohr, *Vaccine* 21:1744-1748, 2003). Therefore, there is the need for a master strain of influenza that will produce high titer influenza virus in cells that have been approved for production of human vaccines.

Summary of the Invention

The present invention discloses methods for producing influenza virus and vaccine compositions by transfecting into a host cell the PB2, PB1, PA, NP and M genes from the A/PuertoRico/8/34 influenza strain, the NS gene from the A/England/1/53 influenza strain and the HA and NA genes from an influenza virus of interest to produce a reassortant influenza virus capable of high titer growth in the host cell. The influenza NS gene encodes two different proteins, NS1 and NS2.

In an embodiment of the present invention, the NS gene has the sequence set forth in SEQ ID NO: 1 or SEQ ID NO: 2. In another embodiment of the present invention the NS1 and NS2 proteins have the sequence set forth in SEQ ID NO: 3 or 4. In a preferred embodiment the NS1 and NS2 proteins have the sequence set forth in SEQ ID NO: 5 or

6. In a preferred embodiment of the present invention NS1 of the original A/England/1/53 protein has amino acid changes at one or more of the following positions relative to SEQ ID NO: 5: 21, 58, 60, 127, 174 or 189 and the deletion of amino acids 231 through 238; and one or more amino changes to positions 16, 31, 86 or 107 of SEQ ID NO: 6 in the NS2 protein. In a most preferred embodiment the amino acid changes are Gln-21 to Arg, Thr-58 to Ile, Val-60 to Ala, Asn-127 to Ser, Val-174 to Ile, Asp-189 to Asn and the deletion of amino acids 231 through 238 in the NS1 protein (Figure 1), and Met-16 to Ile, Met-31 to Ile, Lys-86 to Arg or Phe-107 to Leu in the NS2 protein (Figure 2).

10 These methods utilize mammalian host cells, preferably, mammalian cells which have been approved for human vaccine production, more preferably, Vero cells.

 As an influenza virus of interest, these methods may utilize human, avian, swine or equine influenza viruses. In a preferred embodiment of the present invention the influenza virus of interest is an influenza A virus other than A/England/1/53. The HA and NA genes from any virus may be transfected into cells with the master strain of the present invention to produce a virus strain that grows more efficiently in the host cell.

15 Furthermore, this invention discloses influenza virus and vaccine compositions produced by transfecting into a host cell the PB2, PB1, PA, NP and M genes from the A/PuertoRico/8/34 influenza strain, the NS gene from the A/England/1/53 influenza strain and the HA and NA genes from an influenza virus of interest to produce a reassortant influenza virus capable of high titer growth in the host cell.

 The present invention also discloses a kit containing expression plasmids which contain the PB2, PB1, PA, NP and M genes from the A/PuertoRico/8/34 influenza strain and the NS gene from the A/England/1/53 influenza strain. The expression plasmids from such a kit may be transfected with expression plasmids containing the HA and NA genes from any virus of interest into cells in order to generate a virus capable of high titer growth in a cell line approved for vaccine manufacture.

25 The present invention also discloses methods for producing viruses and vaccines which incorporate a modified A/PuertoRico/8/34 master strain. In the modified A/PuertoRico/8/34 master strain, the NS gene of the original virus is replaced with the NS gene of the A/England/1/53 virus, thus producing a virus master strain capable of

high titer growth in host cells. A host cell is infected with the virus master strain and an influenza virus strain of interest to allow the two strains to reassort, thus producing a different virus subtype that exhibits high growth in the host cell. Alternatively, expression plasmids containing the PB2, PB1, PA, NP and M genes from A/PuertoRico/8/34, the NS gene from A/England/1/53 and the HA and NA genes from an influenza virus of interest are transfected into a host cell to produce a high growth strain of virus.

Description of the Figures and Sequence Listing

Figure 1 shows the alignment of the original A/England/1/53 protein with an A/England 1/53 NS1 protein from a strain adapted to produce high virus yields in Vero cells (A/England/1/53/v-a). The dots in the Vero adapted NS1 sequence (bottom row) indicate that the amino acid at that position is the same amino acid found in the original A/England/1/53 strain (top row). The Vero adapted NS1 sequence differs from the original strain at positions 21, 58, 60, 127, 174, 189, and with the deletion of amino acids 231 through 238 from the Vero adapted protein.

Figure 2 shows the alignment of the original A/England/1/53 protein with an A/England/1/53 NS2 protein from a strain adapted to produce high virus yields in Vero cells (A/England/1/53/v-a). The dots in the Vero adapted NS2 sequence (bottom row) indicate that the amino acid at that position is the same amino acid found in the original A/England/1/53 strain (top row). The Vero adapted NS2 sequence differs from the original strain at positions 16, 31, 86 and 107.

SEQ ID NO: 1 is a sequence listing of the NS gene from the original A/England/1/53 virus.

SEQ ID NO: 2 is a sequence listing of the NS gene from the A/England/1/53/v-a virus or the PR8/Eng-NS virus strain. It encodes the NS1 and NS2 proteins that contain the following changes: Gln-21 to Arg, Thr-58 to Ile, Val-60 to Ala, Asn-127 to Ser, Val-174 to Ile, Asp-189 to Asn and the deletion of amino acids 231 - 238 in the NS1 protein, and Met-16 to Ile, Met-31 to Ile, Lys-86 to Arg or Phe-107 to Leu in the NS2 protein.

SEQ ID NO: 3 is the amino acid sequence of the original A/England/1/53 NS1 protein.

SEQ ID NO: 4 is the amino acid sequence of the original A/England/1/53 NS2 protein.

SEQ ID NO: 5 is the amino acid sequence of the NS1 gene encoded by PR8/Eng-NS or the A/England/1/53/v-a gene. This protein differs from the NS1 protein of the original A/England/1/53 virus in that it contains an Arg-21, Ile-58, Ala-60, Ser-127, Ile-174, Asn-189, and it lacks amino acids 231 through 238.

5 SEQ ID NO: 6 is the amino acid sequence of the NS2 gene encoded by PR8/Eng-NS or the A/England/1/53/v-a gene. This protein differs from the NS2 protein of the original A/England/1/53 virus in that it contains an Ile-16, Ile-31, Arg-86, Leu-107.

Detailed Description of the Invention

10 The present invention provides an influenza virus master strain that produces high titer virus in mammalian cells. Such master strain consists of expression plasmids that contain the PB2, PB1, PA, NP and M genes from the A/PuertoRico/8/34 virus strain and the NS gene from the A/England/1/53 virus strain. The HA and NA proteins from any virus of interest may be combined with such master strain to produce a high titer virus.

15 The present invention also provides reassortant influenza viruses and methods for generating such viruses by transfecting into a host cell expression plasmids that contain the PB2, PB1, PA, NP and M genes from the A/PuertoRico/8/34 virus strain, the NS gene from the A/England/1/53 virus strain, and the HA and NA genes from an influenza virus of interest.

20 Based on the observation of Govorkova EA, et al., J. Infect. Dis. 172(1):250-253, 1995, which described a master strain that produced high titer influenza virus in mammalian cells, applicants undertook studies to identify the molecular changes responsible for the A/England/1/53 vero-adapted (A/England/1/53/v-a) virus' high-yielding phenotype in Vero cells. The goal was to produce an altered A/PuertoRico/8/34
25 vaccine master strain adapted for optimal efficiency of viral rescue in the reverse genetics system for growth in Vero cells. Contrary to what was reported in the Govorkova et al. manuscript, sequence analysis of the complete genome of A/England/1/53/v-a showed that this high-yielding virus contained not only the HA and NA genes from A/England/1/53, but also the NS gene from this same strain. The remaining
30 A/England/1/53/v-a proteins (PB2, PB1, PA, MP and M) had more than 99% nucleotide identity to those of A/PuertoRico/8/34. The NS gene from A/England/1/53/v-a had only

90% identity to the corresponding A/PuertoRico/8/34 gene, the HA gene had 98% identity and the NA gene 97% identity. Therefore, the greatest number of genetic changes between A/England/1/53/v-a and A/PuertoRico/8/34 was in the NS gene.

As used herein, a "reassortant" virus is a virus in which gene segments encoding antigenic proteins from a virus strain of interest (e.g. hemagglutinin and neuraminidase genes) are combined with gene segments encoding viral polymerase complex (PB2, PB1 and PA genes) or other similar genes (e.g., non-glycoprotein genes, including M genes and NS genes, and nucleoprotein (NP) genes) from viruses adapted for growth in culture (or attenuated viruses). The reassortant virus thus carries the desired antigenic characteristics in a background or master strain that permits efficient production in a host cell. Such a reassortant virus is a desirable "virus seed" for production of virions to produce vaccine (see Furminger, In: Nicholson, Webster and May (eds.), Textbook of Influenza, Chapter 24, pp. 324-332). The reassortant virus is preferably purified by a process that has been shown to give consistent results, before being inactivated or attenuated for vaccine production (see, e.g., World Health Organization TRS No. 673, 1982). In the present invention the master strain contains PB2, PB1, PA, NP and M genes from the A/PuertoRico/8/34 virus, NS from the A/England/1/53 virus, and the HA and NA genes from any virus strain.

As used herein, the NS gene originates from the A/England/1/53 virus, an influenza A virus strain obtained from the repository at St. Jude Children's Research Hospital, Memphis, Tennessee, USA. The virus may contain one or more modifications that have been introduced in the noncoding region(s) and/or one or more modifications that have been introduced in the coding region(s). In a preferred embodiment, the NS gene of A/England/1/53 consists of the sequence of SEQ ID NO: 1. In a most preferred embodiment, the NS gene of A/England/1/53 consists of the sequence of SEQ ID NO: 2. The NS1 protein encoded by SEQ ID NO: 1 has the amino acid sequence of SEQ ID NO: 3. The NS1 protein encoded by SEQ ID NO: 2 has the amino acid sequence of SEQ ID NO: 5

As used here in PR8/Eng-NS represents the virus produced when expression plasmids containing 7 genes from A/PuertoRico/8/34 (PB2, PB1, PA, NP, M, HA and NA) were combined with the expression plasmid containing the NS gene from

A/England/1/53/v-a in a virus rescue experiment. Virus rescue is described in Hoffmann et al., Proc. Natl. Acad. Sci. USA, 97:6108-6113, 2000. The NS gene sequence in A/England/1/53/v-a and PR8/Eng-NS are identical (SEQ ID NO:2).

Sequences for the A/PuertoRico/8/34 virus are found in GenBank Accession Nos.
5 NC004518 – NC004525.

A "virus of interest" is any influenza A virus. It can be a virus that produces disease in an animal or a strain of virus a person may wish to study in the laboratory. The strains of viruses include, but are not limited to, human, avian, swine and equine.

"Expression plasmid" is a DNA vector comprising an "inner transcription unit"
10 and an "outer transcription unit". Expression plasmids may be used to generate any type of RNA virus, preferably positive or negative strand RNA viruses, segmented or unsegmented genome RNA viruses or double stranded RNA viruses. Expression plasmids of the present invention may be generated by, but are not limited to, methods disclosed in Neumann et al., Proc. Natl. Acad. Sci. USA 96:9345, 1999 and US patent
15 application 20030035814 or Hoffmann et al., Proc. Natl. Acad. Sci. USA 97:6108-6113, 2000 and US patent application 20020164770.

The term "transfection" or "transfecting" means the introduction of a foreign nucleic acid into a cell so that the host cell will express the introduced gene or sequence to produce a desired polypeptide, coded by the introduced gene or sequence. The
20 introduced gene or sequence may also be called a "cloned" or "foreign" gene or sequence, may include regulatory or control sequences, such as start, stop, promoter, signal, secretion, or other sequences used by a cell's genetic machinery. The gene or sequence may include nonfunctional sequences or sequences with no known function. A host cell that receives and expresses introduced DNA or RNA has been "transformed" and is a
25 "transformant" or a "clone." The DNA or RNA introduced to a host cell can come from any source, including the same genus or species as the host cell, or from a different genus or species.

The present invention contemplates isolation or synthesis of genes encoding influenza viral proteins to be used in the invention, including a full length, or naturally
30 occurring form of an influenza viral protein, and any antigenic fragments thereof from any influenza viral source. As used herein, the term "gene" refers to an assembly of

nucleotides that encode a protein or proteins, and includes cDNA and viral genomic DNA nucleic acids.

An influenza gene of interest, whether viral genomic DNA or cDNA, can be isolated from any subtype of influenza virus. Methods for obtaining an influenza viral hemagglutinin gene, for example, are well known in the art (Sambrook, Fritsch & Maniatis, *Molecular Cloning: A Laboratory Manual*, Second Edition (1989) Cold Spring Harbor Laboratory Press, Cold Spring Harbor, N.Y.). Techniques for isolating viral RNA and transcribing it into cDNA are well known in the art (Hoffmann, et al., *Proc. Natl. Acad. Sci. USA* 97:6108-6113, 2000; Hoffmann, et al., *Arch. Virology* 146: 2275-2290, 2002).

Any influenza virus potentially can serve as the source for the HA and NA genes of interest. The DNA may be obtained by standard procedures known in the art from cloned DNA by chemical synthesis, by cDNA cloning, or by the cloning of genomic influenza viral DNA, or fragments thereof, purified from the desired cell (See, for example, Sambrook, Fritsch & Maniatis, *Molecular Cloning: A Laboratory Manual*, Second Edition (1989) Cold Spring Harbor Laboratory Press, Cold Spring Harbor, N.Y.; Glover, D. M., *DNA Cloning: A Practical Approach*, MRL Press, Ltd., Oxford, U.K. Vol. I, II, 1985).

Cell lines

According to methods for reassorting viruses of the present invention, suitable host cells include embryonated egg cells, Vero cells or other mammalian cells, preferably ones approved and certified according to the WHO requirements for vaccine production (Mizrahi, ed., *Viral Vaccines*, Wiley-Liss, New York, pp. 39-60, 1990). Non-limiting examples of cell lines that can be suitable for methods, viruses and compositions used in the present invention, include, but are not limited to, mammalian fibroblast or cultured epithelial cells as continuous cell lines. Further non-limiting examples include Vero, MDCK, 293T, BK-21 and CV-1 cells, readily available from commercial sources (e.g., ATCC, Rockville, Md.).

WHO certified, or certifiable, continuous cell lines are preferred for producing influenza virus vaccines of the present invention. The requirements for certifying such cell lines include characterization with respect to at least one of genealogy, growth

characteristics, immunological markers, virus susceptibility tumorigenicity and storage conditions, as well as by testing in animals, eggs, and cell culture. Such characterization is used to confirm that the continuous cell lines are free from detectable adventitious agents. In some countries, karyology may also be required. In addition, tumorigenicity is preferably tested in cells that are at the same passage level as those used for vaccine production.

It is preferred to establish a complete characterization of the continuous cell line to be used, so that appropriate tests for purity of the final product can be included. Data that can be used for the characterization of a continuous cell line to be used in the present invention includes (a) information on its origin, derivation, and passage history; (b) information on its growth and morphological characteristics; (c) results of tests of adventitious agents; (d) distinguishing features, such as biochemical, immunological, and cytogenetic patterns which allow the cells to be clearly recognized among other cell lines; and (e) results of tests for tumorigenicity. Preferably, the passage level, or population doubling, of the cell line used is as low as possible.

Vaccines

The present invention provides vaccines and methods for production of influenza vaccines for treating or preventing influenza viral infections. For the production of an influenza vaccine in Vero cells, five plasmids containing the non glycoprotein segments (e.g., PB2, PB1, PA, NP and M) from the high yield strain A/PuertoRico/8/34 and the NS gene from the A/England/1/53 influenza strain are co-transfected with two expression plasmids containing the HA and NA genes of an influenza virus of interest. Virus produced in accordance with the invention can be used in traditional or new approaches to vaccination (see Bilsel and Kawaoka, In: Nicholson, Webster and May (eds.), Textbook of Influenza, Chapter 32, pp. 422-434). In particular, the present invention overcomes defects of current technology, with respect to low influenza virus titers generated in Vero cells.

The present invention permits the rapid development of a high titer desired reassortment virus in Vero cells. Thus, it advantageously positions a vaccine manufacturer to generate a sufficient quantity of vaccine to meet public health needs and ensure standardization, which is an important requirement in the event of a pandemic

when the rapid production of a vaccine is required. Because the vaccines of the invention permit production in an approved cell culture system, they avoid non-specific pathogens, bacteria, and allergenic proteins that may be present in vaccines prepared in embryonated eggs.

5 Adjuvants have been used with vaccines (e.g., influenza vaccines) (see Wood and Williams, In: Nicholson, Webster and May (eds.), Textbook of Influenza, Chapter 23, pp. 317-323). The term "adjuvant" refers to a compound or mixture that enhances the immune response to an antigen. An adjuvant can serve as a tissue depot that slowly releases the antigen and also as a lymphoid system activator that non-specifically
10 enhances the immune response (Hood, et al., Immunology, Second Ed., Benjamin/Cummings: Menlo Park, California, p. 384, 1984). Often, a primary challenge with an antigen alone, in the absence of an adjuvant, is that the antigen will fail to elicit a humoral or cellular immune response. Adjuvants include, but are not limited to, complete Freund's adjuvant, incomplete Freund's adjuvant, saponin, mineral gels such as aluminum
15 hydroxide, surface active substances such as lysolecithin, pluronic polyols, polyanions, peptides, oil or hydrocarbon emulsions, and potentially useful human adjuvants such as BCG (bacille Calmette-Guerin) and Corynebacterium parvum. An example of a preferred synthetic adjuvant is QS-21. Alternatively, or in addition, immunostimulatory proteins can be provided as an adjuvant or to increase the immune response to a vaccine.
20 Preferably, the adjuvant is pharmaceutically acceptable.

 The phrase "pharmaceutically acceptable" refers to molecular entities and compositions that are physiologically tolerable and do not typically produce an allergic or similar untoward reaction, such as gastric upset, dizziness and the like, when administered to a human. Preferably, as used herein, the term "pharmaceutically
25 acceptable" means approved by a regulatory agency of the Federal or a state government or listed in the U.S. Pharmacopeia or other generally recognized pharmacopeia for use in animals, and more particularly in humans. The term "carrier" refers to a diluent, adjuvant, excipient, or vehicle with which the compound is administered. Sterile water or aqueous solution saline solutions and aqueous dextrose and glycerol solutions are preferably
30 employed as carriers, particularly for injectable solutions. Suitable pharmaceutical carriers are described in "Remington's Pharmaceutical Sciences" by E. W. Martin.

Inactivated vaccines

Inactivated virus vaccines are well established for vaccinating against RNA viral infection (e.g., influenza) (see Nichol, In: Nicholson, Webster and May (eds.), Textbook of Influenza, Chapter 27, pp. 358-372). To prepare inactivated virus, the transfected virus is grown either in cell culture or in embryonated eggs. Virus can be inactivated by treatment with formaldehyde, beta-propiolactone, ether, ether with detergent (such as Tween-80), cetyl trimethyl ammonium bromide (CTAB) and Triton N101, sodium deoxycholate and tri(n-butyl) phosphate (Furminger, supra; Wood and Williams, supra). Inactivation can occur after or prior to clarification of allantoic fluid (from virus produced in eggs); the virions are isolated and purified by centrifugation (Furminger, supra, see p. 326). To assess the potency of the vaccine, the single radial immunodiffusion (SRD) test can be used (Schild et al, Bull. World Health Organ., 52:43-50 and 223-31, 1975; Mostow et al., J. Clin. Microbiol., 2:531, 1975). The inactivated vaccine can be administered intramuscularly by injection.

Attenuated live virus

Live, attenuated influenza virus vaccines, using reassortant virus of the invention, can also be used for preventing or treating influenza virus infection, according to known method steps: Attenuation is performed by any method well known in the art, preferably achieved through the use of reverse genetics.

Attenuating mutations can be introduced into influenza virus genes by site-directed mutagenesis to rescue infectious viruses bearing these mutant genes. Attenuating mutations can be introduced into non-coding regions of the genome, as well as into coding regions. Such attenuating mutations can also be introduced into genes other than the HA or NA, e.g., the PB2 polymerase gene (Subbarao et al., J. Virol. 67:7223-7228, 1993). Thus, new viruses can also be generated bearing attenuating mutations introduced by site-directed mutagenesis, and such new viruses can be used in the production of live attenuated reassortants.

It is preferred that such attenuated viruses maintain the genes from the reassortant virus that encode antigenic determinants substantially similar to those of the original virus of interest. This is because the purpose of the attenuated vaccine is to provide substantially the same antigenicity as the original virus of interest, while at the same time

lacking infectivity to the degree that the vaccine causes minimal chance of inducing a serious pathogenic condition in the vaccinated mammal.

Thus, the reassortant virus can be attenuated or inactivated, formulated and administered, according to known methods, as a vaccine to induce an immune response in a mammal. Methods are well-known in the art for determining whether such attenuated or inactivated vaccines have maintained similar antigenicity to that of the original virus of interest. Such known methods include the use of antisera or antibodies to eliminate viruses expressing antigenic determinants of the donor virus; chemical selection (e.g., amantadine or rimantidine); HA and NA activity and inhibition; and DNA screening (such as probe hybridization or PCR) to confirm that genes encoding the antigenic determinants (e.g., HA or NA genes) are not present in the attenuated viruses. See, e.g., Robertson et al., *Giornale di Igiene e Medicina Preventiva* 29:4-58, 1988; Kilbourne, *Bull. M2 World Health Org.* 41:643-645, 969; Aymard-Henry et al., *Bull. World Health Org.* 481:199-202, 1973; Mahy et al., *J. Biol. Stand.* 5:237-247, 1977; Barrett et al., *Virology: A Practical Approach*, Oxford IRL Press, Oxford, pp. 119-150, 1985; Robertson et al., *Biologicals* 20:213-220, 1992.

The vaccines of the present invention may be administered topically, parenterally, transmucosally, e.g. orally, nasally, or rectally, or transdermally. Administration that is parenteral, e.g., via intravenous injection, also includes, but is not limited to, intra-arteriole, intramuscular, intradermal, subcutaneous, intraperitoneal, intraventricular, and intracranial.

The subject of the present invention is also a kit containing reagents according to the invention for the generation of influenza viruses and vaccines. Contents of the kit include, but are not limited to, expression plasmids containing the A/PuertoRico/8/34 genes that encode the PB2, PB1, PA, NP and M genes and an A/England/1/53 NS gene. The kit may contain expression plasmids that contain the HA and NA genes from a particular virus. Expression plasmids containing no virus genes may also be included so that the individual user is capable of incorporating the HA and NA genes from any influenza virus of interest. Mammalian cell lines may also be included with the kit, including but not limited to, Vero and MDCK. Other components such as buffers,

controls, and the like, known to those of ordinary skill in art, may be included in such kits.

The present invention may be better understood by reference to the following non-limiting examples. These examples are presented to more fully illustrate the invention through the description of particular embodiments. These examples should in no way be construed as limiting the scope of the invention.

Example 1

Materials and Methods

Viruses, cells, and plasmids

Influenza viruses were obtained from the repository at St. Jude Children's Research Hospital, Memphis, Tennessee, USA and propagated in 10-day-old embryonated chickens' eggs. MDCK and WHO vaccine-approved Vero cells were obtained from the American Type Culture Collection, and maintained in minimal essential medium (MEM; Invitrogen) containing 10% fetal bovine serum (FBS).

The plasmids encoding the 8 gene segments of the high-growth PR8 virus (pHW191-pHW198) and the HA and NA of A/Panama/2007/99 (pHW444 and pHW446, respectively), A/New Caledonia/20/99 (pHW244 and pHW246, respectively), and A/quail/Hong Kong/G1/97 (pHW409 and pHW422, respectively) have been described (Hoffmann et al., Vaccine 20:3165, 2002). The plasmids encoding the 8 gene segments of A/teal/Hong Kong/W312/97 were the same as those used by Hoffmann et al., Proc. Natl. Acad. Sci. USA 97:6108-6113, 2000.

Viral RNA extraction, reverse-transcriptase polymerase chain reaction (rtPCR), and DNA Sequencing

Total RNA was extracted from virus-infected allantoic fluid by using the RNeasy kit (Qiagen). Production of cDNA and PCR were carried out under standard conditions with previously described primers (Hoffmann, et al., Arch. Virology 146:2275-2289, 2001). The sequence of template DNA was determined by using synthetic oligonucleotides and rhodamine or dRhodamine dye-terminator cycle sequencing ready reaction kits with AmpliTaq DNA polymerase FS (Perkin-Elmer, Applied Biosystems

Inc. [PE/ABI], Foster City, CA). Samples were subjected to electrophoresis, detection, and analysis on PE/ABI model 373, model 373 stretch, or model 377 DNA sequencers.

Viral gene cloning

Full-length cDNA copies of viral genes were amplified by rtPCR as described above. The PCR fragments were cloned into the vector pCRII-TOPO (Invitrogen) according to the manufacturer's instructions. After transformation of TOP10 cells (Invitrogen) and purification of the plasmid by using a plasmid midi kit (Qiagen), the plasmid was digested with the restriction enzyme BsmBI (New England Biolabs) and ligated into the vector pHW2000. All clones were confirmed by full-length sequencing.

10 *Virus rescue from cloned cDNA*

Vero cells were grown to 70% confluency in a 75 cm² flask then trypsinized with trypsin-EDTA (Invitrogen) and resuspended in 10 ml of Opti-MEM I (Invitrogen). To 2 ml of cell suspension was added 20 ml of fresh Opti-MEM I, and 3 ml of this suspension was seeded into each well of a 6-well tissue culture plate (approximately 1 x 10⁶ cells per well). The plates were incubated at 37°C overnight. The following day, 1 µg of each plasmid and 16 µl of TransIT LT-1 (Panvera) transfection reagent were added to Opti-MEM I to a final volume of 200 µl and the mixture incubated at room temperature for 45 min. After incubation, the medium was removed from 1 well of the 6-well plate, 800 µl of Opti-MEM I added to the transfection mix, and this mixture added dropwise to the cells. Six hours later, the DNA-transfection mixture was replaced by Opti-MEM I. Twenty-four hours after transfection, 1 ml of Opti-MEM I containing L-(tosylamido-2-phenyl) ethyl chloromethyl ketone (TPCK)-treated trypsin (0.8 µg/ml) was added to the cells.

The efficiency of virus rescue was calculated by determining the number of plaque-forming units (pfu) in the culture supernatants at various intervals after transfection. The number of pfu's in MDCK cells was determined as previously described (Lau and Scholtissek, Virology 212:225-231, 1995).

Viral growth kinetics in Vero cells

The ability of viruses of different genotypes to grow in Vero cells was determined by analyzing multiple replication cycles. Before infection of Vero cells, the rescued viruses were amplified in 10-day-old embryonated chickens' eggs. Confluent Vero-cell

monolayers grown on 25 cm² plates were washed with phosphate-buffered saline, overlaid with 0.5 ml of diluted virus suspension (to achieve a multiplicity of infection [MOI] of 0.01 pfu/cell), and incubated at room temperature for 60 minutes. The virus suspension was then removed by aspiration and 3 ml of MEM containing 0.4 µg/ml of TPCK-trypsin was added. Twenty-four hours later, another 0.4 µg/ml TPCK-trypsin was added. Sample supernatants were collected at 12-hour intervals until 72 hours after inoculation. The virus titer of the sample was determined by plaque assay on MDCK cells or by hemagglutination assay with 0.5% chicken erythrocytes. Antigenic analysis was performed with polyclonal antisera against PR8 (H1N1), A/New Caledonia/20/99 (H1N1), A/Panama/2007/99 (H3N2), A/teal/ Hong Kong/w312/97 (H6N1), and A/quail/Hong Kong/G1/97 in hemagglutination inhibition assay (Kida, et al., Virology 122:38-47, 1982).

Statistical evaluation of virus replication

The viral growth curves were fitted with logistic function, a nonlinear regression model commonly used for modeling the sigmoid growth curves in biology and chemistry (Davidian and Gilitinan, Nonlinear Models for Repeated Measurement Data. Chapman & Hall, New York, 1996; O'Connel, et al., Chemometrics and Intelligent Laboratory Systems 20:97-114, 1993; Pinheiro and Bates, Mixed-Effects Model in S and S-PLUS, Springer, New York, 2000). The logistic function in this analysis is given by $\text{Ln}(\text{Viral Titers}) = \frac{\theta_1}{1 + \exp[(\theta_2 - t)/\theta_3]}$ where t is the time post inoculation (in hour); θ_1 is the peak titers (in Ln(pfu/ml)); θ_2 is the half time to peak titers; and θ_3 is the time from half to 73% peak titers. The model was fitted using a nonlinear least square procedure (1) implemented with statistical software S-PLUS (Pinheiro and Bates, Mixed-Effects Model in S and S-PLUS, Springer, New York, 2000). Each growth curve was fitted with data of three replicate experiments. Based on the estimates of parameters and their standard errors from fitted models, the parameters for different strains of viruses (PR8, PR8/Eng-NS, and W312) were compared using t-tests. Viral titers of A/PuertoRico/8/34 and PR8/Eng-NS were also compared with two-way analysis of variance (ANOVA) method separately at 12, 24, 36, and 48 hours post inoculation. The two factors of the two-way ANOVA are virus type and master strain backbone.

Results

The Effect of the NS gene of A/England/53/v-a on the efficiency of virus rescue from cDNA in Vero cells

The NS gene from A/England/1/53/v-a was cloned into the expression plasmid, pHW2000. One experiment contained the plasmids necessary to rescue

5 A/PuertoRico/8/34, another to rescue a reassortant virus containing 7 genes of A/PuertoRico/8/34 and the NS gene of A/England/1/53/v-a ("PR8/Eng-NS"). The supernatants of each virus rescue experiment were assayed for viral titers at 12 hour intervals. The results showed that the rescue efficiency of the PR8/Eng-NS virus was superior to that of A/PuertoRico/8/34 at 12, 24 and 36 hours post transfection ($p < 0.001$ by ANOVA analysis) demonstrating that the gene product(s) of the NS gene can
10 influence viral growth characteristics in Vero cells. There was no significant difference between viral titers at times over 36 hours post transfection. The half time to peak titer was significantly ($P < 0.0001$) reduced for PR8/Eng-NS when compared to that for A/PuertoRico/8/34 (17.8 ± 0.6 hours and 22.9 ± 0.7 hours, respectively).

15 To assess the suitability of the PR8/Eng-NS virus as a master strain for vaccine purposes, similar experiments were conducted in which the HA and NA of contemporary viruses were rescued. The HA and NA from H1N1 (A/New Caledonia/20/99), H3N2 (A/Panama/2007/990), H6N1 (A/teal/Hong Kong/W312/97) and H9N2 A/quail/Hong Kong/G1/97 viruses reassorted onto the A/PuertoRico/8/34 and PR8/Eng-NS backbones
20 using reverse genetics in Vero cells. All the HA and NA combination were rescued on both backbones, although the kinetics of virus rescue was faster with the PR8/Eng-NS viruses.

Effects of the NS gene from Eng53/v-a on growth characteristics of PR8 in Vero cells

25 To assess the effect of the replacement of the NS gene in A/PuertoRico/8/34 on subsequent virus amplification in Vero cells triplicate samples of near-confluent Vero cells were infected with A/PuertoRico/8/34 and PR8/Eng-NS at a low MOI (0.01) and virus replication followed by assaying culture supernatant every 12 hours. PR8/Eng-NS had a significantly ($P < 0.0001$) lower half time to peak titer than did A/PuertoRico/8/34
30 (16.8 ± 0.6 hours and 25.3 ± 0.7 hours, respectively) although there was no significant difference in peak titers (1.6×10^7 pfu/ml and 1.2×10^7 pfu/ml, respectively). Thus, the

growth characteristics of A/PuertoRico/8/34 in Vero cells are improved by inclusion of the NS gene of A/England/1/53/v-a. Similar experiments were conducted with recombinant A/PuertoRico/8/34 and PR8/Eng-NS viruses carrying the surface glycoproteins of A/New Caledonia/20/99 (H1N1), A/Panama/2007/99 (H3N2),
5 A/teal/Hong Kong/W312/97 (H6N1), and A/quail/Hong Kong/G1/97 (H9N2). The half times to peak virus yield were significantly ($P < 0.0001$) lower in all PR8/Eng-NS viruses than in their A/PuertoRico/8/34 counterparts. Thus showing that the half time to peak yield of different subtypes of influenza virus in Vero cells is reduced by inclusion of the NS gene of A/England/1/53/v-a. The peak titers of the PR8/Eng-NS viruses carrying the
10 surface glycoproteins of the A/New Caledonia/20/99 and A/Panama/2007/99 viruses were significantly higher ($P < 0.005$) than those of the A/PuertoRico/8/34 viruses. The increase in growth kinetics in Vero cells did not affect the ability of the reassortant viruses to grow in eggs. The PR8/Eng-NS variants all grew to equivalent HA titers in eggs as their A/PuertoRico/8/34 counterparts.

15 In a related experiment the growth characteristics, in Vero cells, of 2 reverse-genetics derived viruses containing the HA and NA genes of A/teal/Hong Kong/W312/97 (W312) were compared with those of the reverse genetics derived wild-type W312. The remaining gene segments of the 2 variants were from A/PuertoRico/8/34 or PR8/Eng-NS. Although the peak titers of all 3 viruses at 72 hours were similar, the half times to
20 peak titer were significantly ($P < 0.0001$) shorter for the A/PuertoRico/8/34 and PR8/Eng-NS variants (29.3 ± 1.0 and 20.7 ± 0.8 hours, respectively) than for W312 (60.3 ± 4.5 hours).

To test whether changes in genes other than NS could lead to further improvements in the growth characteristics of PR8/Eng-NS, we determined the growth
25 characteristics of A/PuertoRico/8/34, Eng53/v-a, and PR8/Eng-NS in Vero cells. If further improvements were possible, they would be indicated by Eng53/v-a having superior growth characteristics to PR8/Eng-NS. The growth characteristics of Eng53/v-a and PR8/Eng-NS were substantially better than those of A/PuertoRico/8/34 but indistinguishable from each another. This result suggests that the high-yielding
30 phenotype of Eng53/v-a is due solely to the NS gene.

Stability of viruses rescued from Vero cells

Vaccine-production procedures must allow the virus produced to retain the antigenic properties of the parent viruses. Any benefit from an increase in yield would be negated by changes in the antigenicity of a vaccine. To determine whether antigenic changes occurred upon rescue of viruses in Vero cells we used hemagglutination inhibition assays to compare the antigenic profiles of the rescued PR8/Eng-NS viruses with their wild-type counterparts. All PR8/Eng-NS rescued viruses were antigenically indistinguishable from the corresponding wild-type viruses. To confirm the genetic stability of the PR8/Eng-NS rescued viruses, we compared the HA gene sequences of the rescued and wild-type viruses. We found no changes in any of the viruses. This result demonstrates that introduction of the NS gene from Eng53/v-a into the PR8 vaccine master strain does not lead to changes in the HA gene.

Discussion

Recent discoveries in influenza pathogenicity and reverse genetics have the potential to revolutionize the way pandemic and interpandemic influenza vaccines are prepared and manufactured. Much of this technology has, however, been confined to experimental protocols; the realization of this potential awaits refinements of the methods. By incorporating the NS gene of Eng53/v-a into the standard A/PuertoRico/8/34 vaccine master strain, we have shown a reproducible improvement in vaccine-virus rescue and growth in Vero cells with no drop in egg titers. Although these viruses were rescued with the standard A/PuertoRico/8/34 vaccine strain, the improved efficiency of rescue with the PR8/Eng-NS system may be crucial with other HA and NA combinations that are poorly infective in Vero cells.

With each of the HA and NA subtypes tested, the PR8/Eng-NS viruses reached peak titers significantly faster than did the corresponding A/PuertoRico/8/34 virus. The peak titers of the PR8/Eng-NS variants containing the surface glycoproteins of the 2 contemporary vaccine strains (A/New Caledonia/20/99 and A/Panama/2007/99) and of A/teal/Hong Kong/W312/97, a virus implicated in the genesis of the 1997 H5N1 human viruses (Hoffmann, E. J. et al., *Virology* 74:6309-6315, 2000), were also significantly higher than those of the PR8 viruses. In contrast, there was no difference in the peak titers of the PR8/Eng-NS and A/PuertoRico/8/34 viruses carrying the surface glycoproteins of A/quail/Hong Kong/G1/97 or A/PuertoRico/8/34 itself. However, by the time these peak

titers were reached with the A/PuertoRico/8/34 variants, the cells infected with the PR8/Eng-NS variants had been completely destroyed by cytopathic effects and a manufacturing process in which cells and fresh media can be continually added or replenished is likely to produce higher yields for those viruses on the PR8/Eng-NS backbone.

This data also provides support for the continued use of 6+2 high-growth reassortants for vaccine production in Vero cells. For example, the PR8/Eng-NS variant of the H6N1 virus had significantly superior growth characteristics to those of the wild-type H6N1 virus; the estimates of half times to peak titers were 3 times longer in the wild-type virus. The use of 6+2 reassortants also reduces the risks of growing adventitious agents with influenza viruses isolated directly from clinical samples.

One of the benefits of cell-based production of vaccines is that it appears to allow the properties of influenza virus HA molecules to remain unchanged; these molecules are altered during the adaptation of viruses to eggs (Katz, J.M., et al., *Virology* 156:386-395, 1987; Robertson, J.S., *Virology* 143:166-174, 1985; Schild, J.H., et al, *Nature* 303:706-709, 1983). We found that the HA genes of the PR8/Eng-NS-derived viruses were the same before and after rescue and propagation from Vero cells. This stability is an advantage in a vaccine that derives much of its protective qualities from the production of neutralizing antibody directed against the HA molecule. However, such benefits will be lost unless candidate vaccine viruses are first isolated in approved cell lines rather than the widely used MDCK cells or eggs.

Host range in influenza viruses is a polygenic trait, for which many influenza proteins have been implicated (Hatta, M., et al, *Virology* 295:250-255, 2002; Scholtissek, C., et al., *Virology* 147:287-294, 1985; Snyder, M.H., et al., *Virus Res.* 15:69-83, 1990; Tian, S.F., et al., *J. Virology* 53:771-775, 1985). Likewise, many genes, including the NS gene, have been implicated in the attenuation of influenza viruses in different hosts (Clements, M.L., *J. Clin. Microbiology* 30:655-662, 1002; Maassab, H.F. and DeBorde, D.C., *Virology* 130:342-350, 1983; Snyder, M.H., et al., *Virus Res.* 15:69-83, 1990). However, in our system, the transfer of the NS gene from Eng53/v-a to A/PuertoRico/8/34 was alone sufficient to confer the high-growth phenotype. Although many factors have been reported to determine the efficiency of growth of influenza

viruses, the NS1 protein (1 of the 2 proteins expressed by the NS gene) is thought to play a significant role in translation and replication. For example, NS1 and its interaction with host proteins have been reported to play central roles in inhibiting the nuclear export and splicing of host mRNA (Fortes, P., *EMBO J.* 13:704-712, 1994; Nemeroff, M.E., *Mol.*

5 Cell 1:991-1000, 1998; Qiu, Y. and Krug, R.M., *J. Virology* 63:2425-2432, 1994; Qui, Y., et al., *RNA* 1:304-316, 1995; Wang, W. and Krug, R.M., *RNA* 4:55-64, 1998; Wolff, T., et al., *J. Virology* 72:7170-7180, 1998). Furthermore, NS1 protein plays an important role in regulating interferon activity (Seq, S. H., et al., *Nat. Med.* 8:950-954, 2002). It is unlikely, however, that the interferon pathway is involved in viral growth in Vero cells, because Vero cells do not produce interferon (Diaz, M.O., et al., *Proc. Natl. Acad. Sci. USA* 85:5259-5263, 1988). Another study failed to identify major changes in the shutoff of host protein synthesis or in viral protein expression in Vero cells after infection with NS1 deletion-mutant viruses (Salvatore, M., et al., *J. Virology* 76:1206-1212, 2002). Garcia-Sastre et al. showed, however, that a mutant virus that did not express NS1
15 protein (delNS1) grew approximately 10 times slower on Vero cells than did the wild-type strain (Garcia-Sastre, A., et al., *Virology* 252:324-330, 1998). The second protein encoded by the NS gene is the NS2 or nuclear export protein (NEP). Although little is known about the function of NEP, this polypeptide interacts with nucleoprotein and contributes to the nuclear export of the viral ribonucleoproteins (O'Neill, R.E., et al.,
20 *EMBO J.* 17:288-296, 1998). Additionally, amino acid residues of the NEP have been shown to be crucial for viral replication (Bullido, R., et al., *J. Virology* 75:4912-4917, 2001). Studies are ongoing to identify the NS gene products responsible for increased viral replication in Vero cells and the mechanisms involved.

The applicability of reverse genetics to the production of influenza vaccines
25 depends on the use of a suitable cell culture system. Technical constraints and the limited number of cells licensed for vaccine production severely limit the options available. It is therefore likely that timely improvements in reverse genetics derived vaccines will arise from optimization of current protocols rather than identification of alternative systems. The use of the Vero-cell system with an improved master strain virus is a viable option
30 for the rapid manufacture of influenza vaccines in pandemic emergencies and for the production of vaccines during annual epidemics.